Impact analysis of a flexible air transportation system: Clip-Air

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Outline

1. Flexibility
2. Schedule Planning Model
3. Comparative Analysis
4. Conclusions

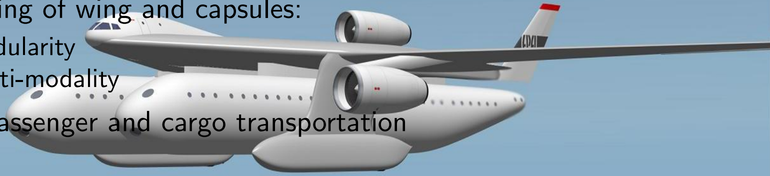
Outline

Flexibility

- Flexibility in transportation systems
  - Robustness
  - Demand responsiveness

- Rail transportation $\Rightarrow$ modularity in fleet
- Maritime transportation $\Rightarrow$ standard unit loads, multi-modality
- Air transportation $\Rightarrow$ decision support systems

Flexibility of Clip-Air



- Decoupling of wing and capsules:
  - Modularity
  - Multi-modality
- Mixed passenger and cargo transportation

- ... and can be combined with intelligent decision support tools:
  - Demand management
  - Disruption management

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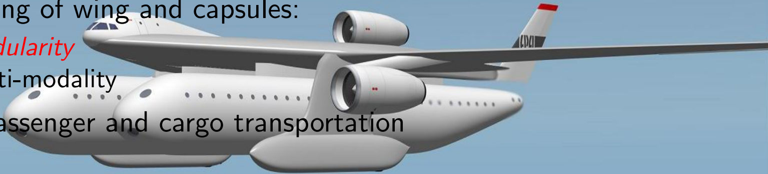

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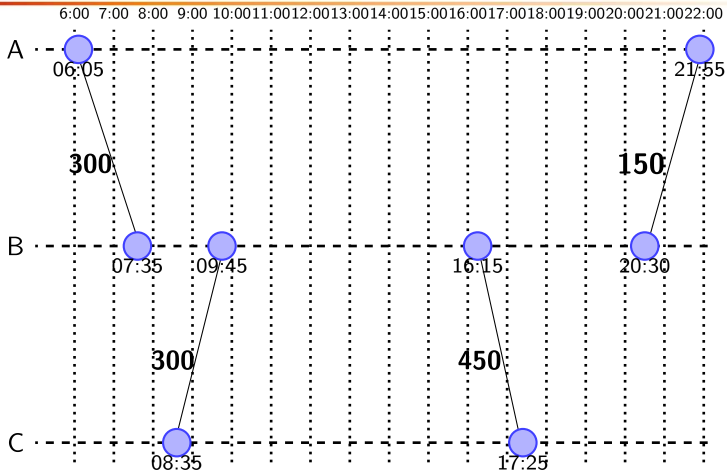
Illustration - Modularity



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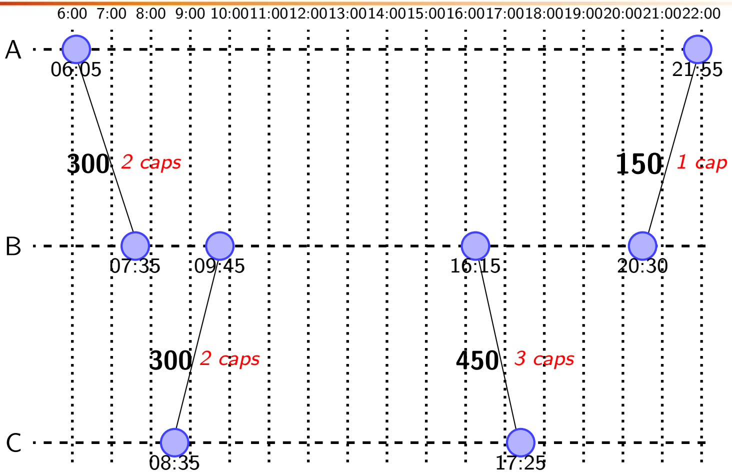

Outline

Model framework

- Decisions
  - Fleet assignment
    - Assignment of wings to the flights
    - Assignment of capsules to the wings
  - Schedule - selected optional flights
  - Seat allocation to economy and business class
  - The spilled number of passengers
- Supply-demand interactions demand model
  - Spill and recapture
  - Itinerary choice model

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    Demand management

Integrated schedule planning model

$$Min \sum_{f \in F} (C_f^w x_f^w + \sum_{k \in K} C_{k,f} x_{k,f}) + \sum_{h \in H} \sum_{s \in S^h} \sum_{i \in (I_s \setminus I_s')} (\sum_{j \in I_s} t_{i,j} - \sum_{j \in (I_s \setminus I_s')} t_{j,i} b_{j,i}) p_i \; \textit{op. costs + loss of pax.} \quad (1)$$

$$s.t. \sum_{k \in K} x_{k,f} = 1 \; \textit{mandatory flights} \quad \forall f \in F^M \quad (2)$$

$$\sum_{k \in K} x_{k,f} \leq x_f^w \; \textit{wing-capsules} \quad \forall f \in F \quad (3)$$

$$y_{a,t^-}^w + \sum_{f \in In(a,t)} x_f^w = y_{a,t^+}^w + \sum_{f \in Out(a,t)} x_f^w \; \textit{flow cons. wings} \quad \forall [a,t] \in N \quad (4)$$

$$\sum_{a \in A} y_{a,\mathrm{minE}_a^-}^w + \sum_{f \in CT} x_f^w \leq R_w \; \textit{available wings} \quad (5)$$

$$y_{a,minE_a^-}^w = y_{a,maxE_a^+}^w \; \textit{cyclic wings} \quad \forall a \in A \quad (6)$$

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$$\sum_{s\in S^h}\sum_{i\in(I_s\setminus I_s')}\delta_f^i D_i - \sum_{j\in I_s}\delta_f^i t_{i,j} + \sum_{j\in(I_s\setminus I_s')}\delta_f^i t_{j,i} b_{j,i} \leq \pi_{f,h} \textit{ demand-supply} \qquad \forall f\in F, h\in H \tag{10}$$

$$\sum_{h\in H}\pi_{f,h} \leq \sum_{k\in K} Q\ k\ x_{k,f} \textit{ available seats} \qquad \forall f\in F \tag{11}$$

$$\sum_{j\in I_s} t_{i,j} \leq D_i \textit{ spilled passengers} \qquad \forall h\in H, s\in S^h, i\in(I_s\setminus I_s') \tag{12}$$

$$x_f^w \in \{0,1\} \qquad \forall f\in F \tag{13}$$

$$x_{k,f} \in \{0,1\} \qquad \forall k\in K, f\in F \tag{14}$$

$$y_{a,t}^w \geq 0 \qquad \forall [a,t]\in N \tag{15}$$

$$y_{a,t}^k \geq 0 \qquad \forall [a,t]\in N \tag{16}$$

$$\pi_{f,h} \geq 0 \qquad \forall f\in F, h\in H \tag{17}$$

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Outline

Configuration - Comparison with Airbus A320

		Clip-Air	A320
Maximum Capacity		3x150(450 seats)	150 seats
Engines		**3** engines	**2** engines
Maximum	1 (plane/capsule)	139t (+78%)	78t
Aircraft Weight	2 (planes/capsules)	173.5t (+11%)	2x78t (156t)
	3 (planes/capsules)	208t (-11%)	3x78t (234t)

Operating costs for *Clip-Air*

- Based on standard flight operating costs
- Adjustment based on weight differences:
  - Fuel costs [1] (25.3%)
  - Airport and air navigation charges[2] (6%)
- Crew cost [1] (24.8%) is separated between wing (flight crew) and capsules (cabin crew):
  - flight crew constitutes a 60% of the total crew cost
  - gain of 30% with 2 capsules
  - gain of 40% with 3 capsules

[1] IATA,2010
[2] Castelli and Ranieri, 2007; ICAO, 2012

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- Only passenger transportation

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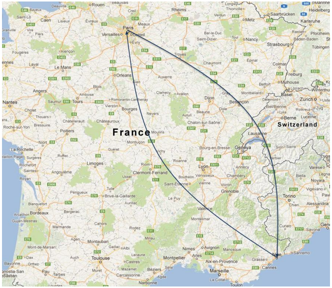
- Only passenger transportation
- Total fleet investment cost is ignored
- The schedule and the demand is assumed to remain the same

Towards results

- Input: data from a major European airline company
  - set of optional and mandatory flights
  - set of airports
  - set of itineraries: demands and fares
  - set of aircraft for the standard fleet
- Performance measures
  - ASK: available seat kilometers
  - TPASK: transported pax. per available seat kilometers
- Tests:
  - Network effect
  - Fleet composition
  - Available capacity
  - Sensitivity analysis on the costs

Network effects - Airport pair

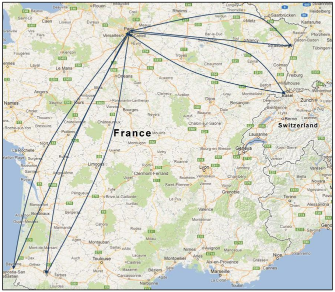
Data		
Airports		2
Flights		38
Density (Flights/route)		19
Passengers		13,965
Itineraries		45
Standard fleet types		A320(150), A330(293), B747-200(452)
Results		
	Standard fleet	Clip-Air
Operating cost	1,607,166	1,725,228
Spill costs	604,053	448,140
Revenue	2,419,306	2,575,219
Profit	**812,140**	**849,991 (+4.66 %)**
Transported pax.	**10,276**	**11,035 (+7.39 %)**
Flight count	38	38
Total flight duration	3135 min	3135 min
Used fleet	2 A320	7 wings
	5 A330	12 capsules
Used aircraft	7	7
Used seats	1765	1800
ASK	78,388,063	79,942,500
TPASK $(\times 10^{-5})$	13.11	13.80



Clip-Air does not have any advantage in terms of the aircraft size

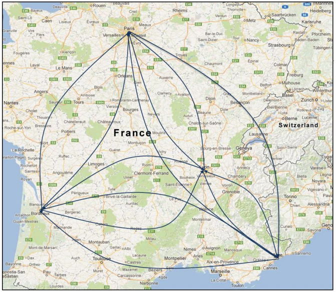
Network effects - Hub and spoke

Data		
Airports		5
Flights		26
Density (Flights/route)		3.25
Passengers		9,573
Itineraries		37
Standard fleet types		A320(150), A330(293), B747-200(452)
Results		
	Standard fleet	Clip-Air
Operating cost	817,489	938,007
Spill costs	484,950	393,677
Revenue	1,247,719	1,338,992
Profit	**430,230**	**400,985 (- 6.80 %)**
Transported pax.	**5,031**	**5,721 (+ 13.71 %)**
Flight count	**24**	**22**
Total flight duration	**1850 min**	**1700 min**
Used fleet	5 A320	6 wings
	2 A330	12 capsules
	1 B747	
Used aircraft	**8**	**6**
Used seats	1788	1800
ASK	**46,860,500**	**43,350,000**
TPASK $(\times 10^{-5})$	**10.74**	**13.20**



Network effects - Peer-to-peer network

Data		
Airports		4
Flights		98
Density (Flights/route)		8.17
Passengers		28,465
Itineraries		150
Standard fleet types		A320(150), A330(293), B747-200(452)
Results		
	Standard fleet	Clip-Air
Operating cost	3,189,763	3,117,109
Spill costs	982,556	978,683
Revenue	5,056,909	5,060,782
Profit	**1,867,146**	**1,943,673 (+ 4.1 %)**
Transported pax.	**20,840**	**21,424 (+ 2.8 %)**
Flight count	91	84
Total flight duration	6650 min	6160 min
Used fleet	7 A320	13 wings
	10 A330	28 capsules
	3 B747	
Used aircraft	20	13
Used seats	**5336**	**4200 (- 21.3 %)**
ASK	**502,695,667**	**366,520,000**
TPASK ($\times 10^{-}5$)	**4.15**	**5.85**

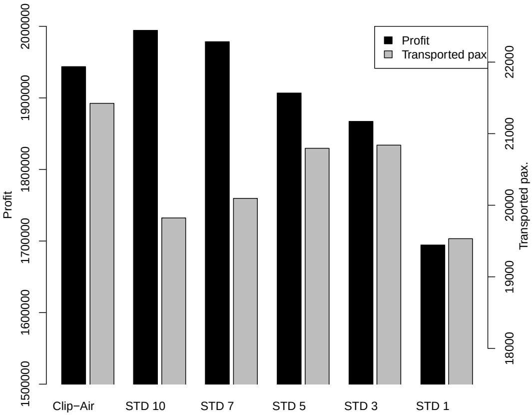


Network effects

- Enhanced performance when...
  - High flight density
  - Well connected network

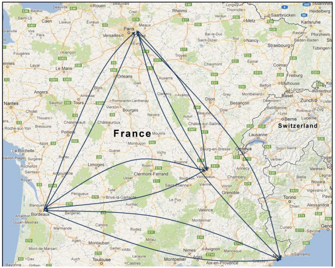
Fleet composition

The same data as peer-to-peer network



Available capacity

Airports	5
Flights	100
Density (Flights/route)	6.25
Passengers	35,510
Itineraries	140
Standard fleet types	A319(124), A320(150), A321(185), A330(293), A340(335), B737-300(128), B737-400(146), B737-900(174), B747-200(452), B777(400)



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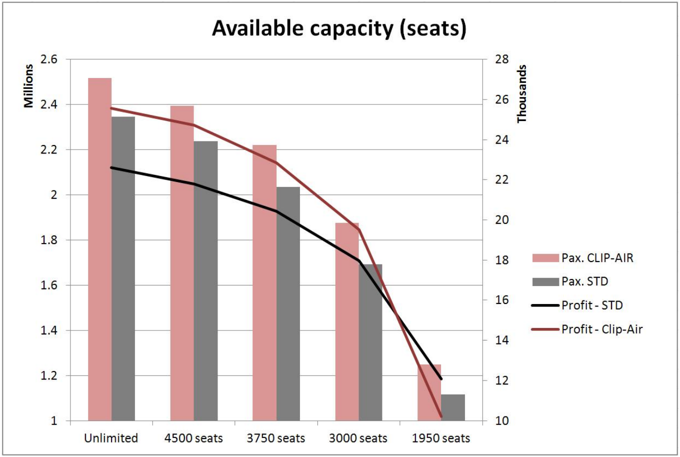
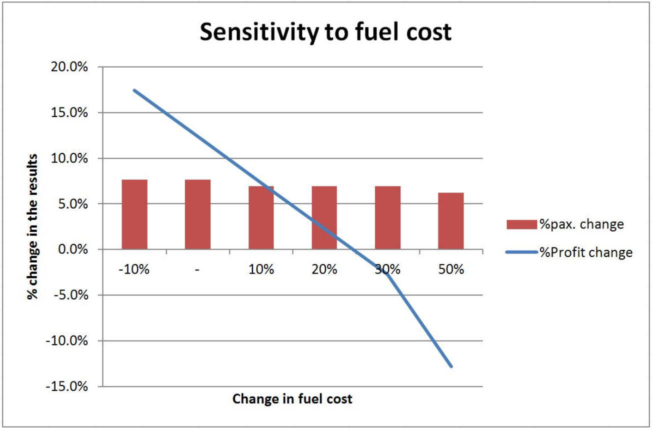


Sensitivity analysis on the cost of Clip-Air

The same data used for the test on the available capacity



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- Atasoy, B., Salani, M., Bierlaire, M., and Leonardi, C. (to appear in 2013 April). Impact analysis of a flexible air transportation system, European Journal of Transport and Infrastructure Research 13(2).

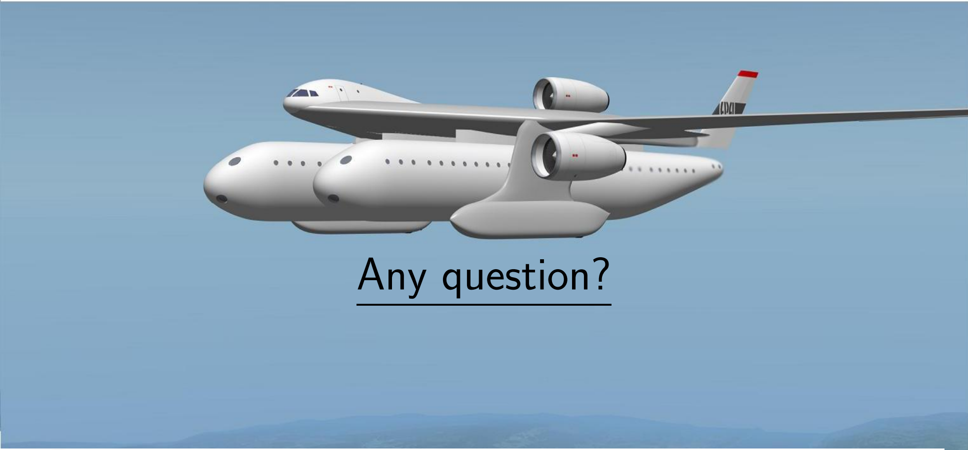
Different wing and capsule sizes

- Clip-Air has a strength with one single wing/capsule type
- Different sizes can be studied
- Small wings/capsules: easier transport

Multi-modality of Clip-Air capsules

- Clip-Air capsules can be transfered via other means of transport
- Empty capsule management
- Demand fluctuations
- Unbalanced demand
- European market - railways

Thank you very much for your attention!



Any question?

Spill and recapture ▸ Model

$$
\begin{aligned}
V_i = &-[2.23(\text{-}3.48) \times \text{nonstop}_i + 2.17(\text{-}3.48) \times \text{stop}_i] \times \ln(p_i/100) \\
&-[0.102(\text{-}2.85) \times \text{nonstop}_i + 0.0762(\text{-}2.70) \times \text{stop}_i] \times \text{time}_i \\
&+0.0283(1.21) \times \text{morning} \qquad \forall i \in I_s, s \in S^{econ.},
\end{aligned}
$$

$$
\begin{aligned}
V_i = &-[1.97(\text{-}3.64) \times \text{nonstop}_i + 1.96(\text{-}3.68) \times \text{stop}_i[\times \ln(p_i/100) \\
&-[0.104(\text{-}2.43) \times \text{nonstop}_i + 0.0821(\text{-}2.31) \times \text{stop}_i] \times \text{time}_i \\
&+0.0790(1.86) \times \text{morning} \qquad \forall i \in I_s, s \in S^{bus.},
\end{aligned}
$$

$$
b_{i,j} = \frac{\exp(V_j)}{\sum_{k \in I_s \setminus \{i\}} \exp(V_k)} \qquad \forall h \in H, s \in S^h, i \in (I_s \setminus I_s^{'}), j \in I_s,
$$

Spill and recapture

	class	nonstop	morning	time	price	V
A-B_1	E	0	1	250	300	-2.67
A-B_2	E	0	0	250	300	-2.70
A-B_3	E	1	0	80	200	-1.68
A-B_4	E	1	1	80	200	-1.65
A-B'	E	1	1	80	225	-1.92

	A-B_1	A-B_2	A-B_3	A-B_4	A-B'
A-B_1	-	0.113	0.314	0.323	0.250
A-B_2	0.116	-	0.314	0.322	0.248
A-B_3	0.146	0.141	-	0.403	0.310
A-B_4	0.147	0.143	0.396	-	0.314